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Experimental studies, including high pressure closed chamber combustion tests and gun firings, were performed on a series of propellant formulations containing a boron hydride salt. Samples consisted of a Kraton binder, RDX oxidizer and boron hydride fuel. Booster-aided combustion tests using a specially designed closed bomb fixture indicated that these samples could exhibit desired burning properties for a traveling charge propellant application. Gun firings indicate that with adequate ignition control it is possible to tailor the gun pressure-time profiles in the desired direction to increase down-bore acceleration and demonstrate the traveling charge effect.

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I. INTRODUCTION

The traveling charge concept has long fascinated interior ballisticians interested in hypervelocity propulsion. This concept, originally introduced by Langweiler[1] as an "Impulse Gun," is theoretically capable of producing muzzle velocities in the 2-3 km/s regime without a large increase in maximum operating pressure. A number of traveling charge (TC) projects have been undertaken to try to realize this increase in muzzle velocity. The reader is referred to reports by Vest,[2] O'Donnell,[3] Baer,[4] and Baldini[5] for experimental results on various propellant and gun configurations. There have also been a number of theoretical feasibility studies done on the topic by Lee,[6] Vinti,[7] and Barbarek.[8] In his preparations for the current Ballistic Research Laboratory (BRL) TC program, May[9] compiled a comprehensive review on the subject.

A somewhat simplistic view of the traveling charge effect is pictured[10] in Figure 1. A very high burning rate (VHBR) propellant is attached to a projectile and is given an initial acceleration or boost from a conventional propellant. The VHBR ignites after a slight delay to provide a continuous base pressure and thrust to the projectile until muzzle exit.

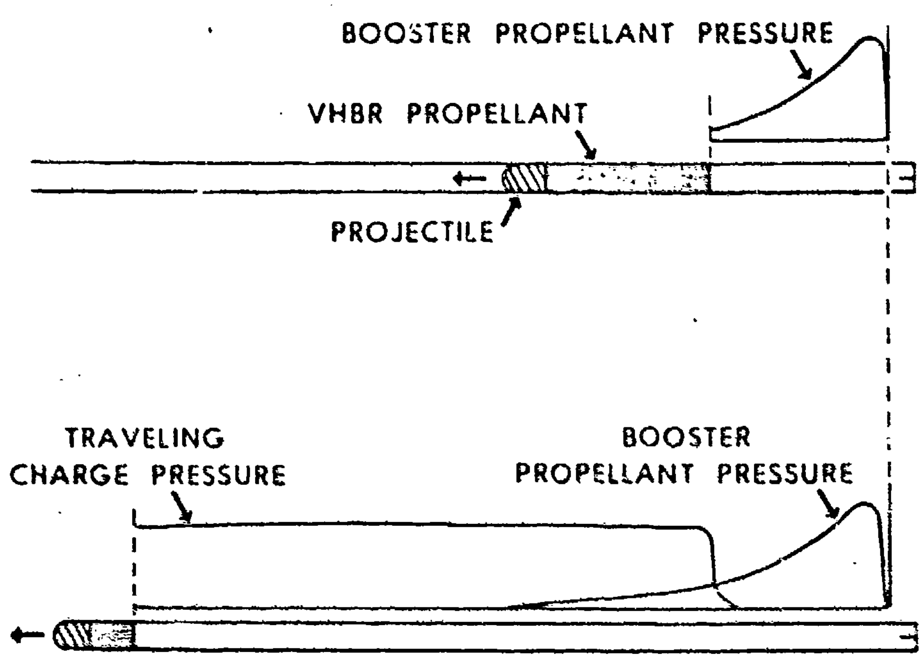

Figure 1. Schematic of Traveling Charge Concept

In the late 1970's, BRL initiated a propellant development effort in support of TC. Some of the resulting VHBR propellants had apparent burning rates as high as 500 m/s as measured in the closed bomb. Unfortunately, handling hazards involving some of the fast burning formulations interrupted gun tests before adequate ballistic studies could be conducted. BRL's efforts in the last several years have centered on research into safer propellant formulations, combustion diagnostics and theoretical interior ballistic studies. Based on developments in these areas, the decision was made to reinitiate the traveling charge feasibility study.

Two important decisions have helped to move the project in the desired direction; rescaling of the TC gun fixture, and changes in the propellant combustion screening methodology. In earlier studies, combustion screening was done on 12.7-mm diameter samples, while interior ballistic studies were carried out in a 40-mm gun. This required sample scale-up prior to ballistic testing. In the current approach, the gun was scaled down to permit use of the half-inch diameter samples for both combustion and interior ballistic tests. This eliminated any potential changes in combustion behavior associated with changing propellant diameter. It also minimized the time and cost of obtaining separate propellant samples for gun firings. The second important decision concerned combustion screening methods. In earlier combustion tests, samples were burned in the closed bomb using a small igniter charge. This is analogous to a traveling charge gun firing where the propelling charge consists entirely of the TC element. Interior ballistic computations,[11] however, indicated that optimum TC performance would most likely be achieved by using a conventional booster charge to initially accelerate the projectile/TC element. In such a scenario, the TC propellant would be burning under pressurization by the booster. To mimic this condition, a new closed bomb combustion test method was developed in which the VHBR propellant was pre-pressurized by the hot combustion products of a conventional granular propellant.

The objective of the present paper is to report the results of combustion diagnostics in a closed chamber and interior ballistic test firings of several traveling charge formulations. In addition, comparisons of experimental ballistic data with computed results are included. Complete details of the interior ballistic computations are covered in a related paper.[12]

II. COMBUSTION DIAGNOSTICS

1. BACKGROUND

Combustion characteristics of various candidate traveling charge formulations have been reported[13] discussing possible combustion mechanisms involved in the burning of these (VHBR) boron-hydride compounds. Some evidence has been presented that the reaction starts with a porous or in-depth burning zone followed by deconsolidation, leading to very high solid-to-gas conversion rates. These studies were

carried out at relatively low pressures during closed chamber testing in which pressurization was brought about solely by the VHBR formulation.

The ballistic cycle for the traveling charge concept under consideration will be started by a conventional booster charge which will initiate the ballistic cycle and generate the peak operating pressure. After the projectile has moved a short distance, the TC, attached to the base of the projectile, will ignite and burn as the projectile moves down bore increasing its velocity by thrust and a higher base pressure. Consequently, the TC will be ignited and burn near peak pressure conditions. It makes more sense, therefore, to test the combustion properties of the VHBR formulations under these conditions. Based on projected muzzle velocities and barrel dimensions for the 14-mm test gun, estimated burn times of 0.5 to 2 ms are required for TC charges from 25-50 mm in length. Since the intent is to make the TC turn on after maximum pressure, combustion reproducibility requirements are expected to be less stringent than for the booster charge. The exact reproducibility requirements will be based on interior ballistic calculations. Gun firings will be the final proof of acceptability.

2. EXPERIMENTAL

A closed chamber (210 cm^3) was modified with an insert containing a 13-mm diameter cavity to simulate the projectile-barrel configuration. (Figure 2).

A sample was placed in this cavity and ignited with a booster charge (single perforated M10 or Hercules Unique) located in the main chamber. The booster charge produced peak chamber pressures of 180 or 360 MPa. The sample was either held fixed by epoxy in the cavity or was greased on the sides so that it was free to move during combustion. In an actual TC configuration it was not obvious how the propellant should be attached to the projectile. This test was designed to see if combustion was influenced by the technique used. An ignition delay device, consisting of a disc of conventional propellant (NOSOL 265, 1 mm thick) was attached to the surface of the TC to delay the start of combustion until after peak pressure. Silicone grease was used to fill in the remaining gaps on the front surface. Burn times for the TC could then be found from the pressure histories. It was believed that these tests would simulate the TC gun environment better. Since the propellants did not appear to burn in a strictly laminar fashion at low pressure, and it was not known how pressure would effect this combustion, it became necessary to carry out combustion tests with high pre-pressurization to determine VHBR propellant burn times for the TC application. Samples were heavily confined on the sides to simulate the experimental confinement of the gun tube expected in the ballistic tests.

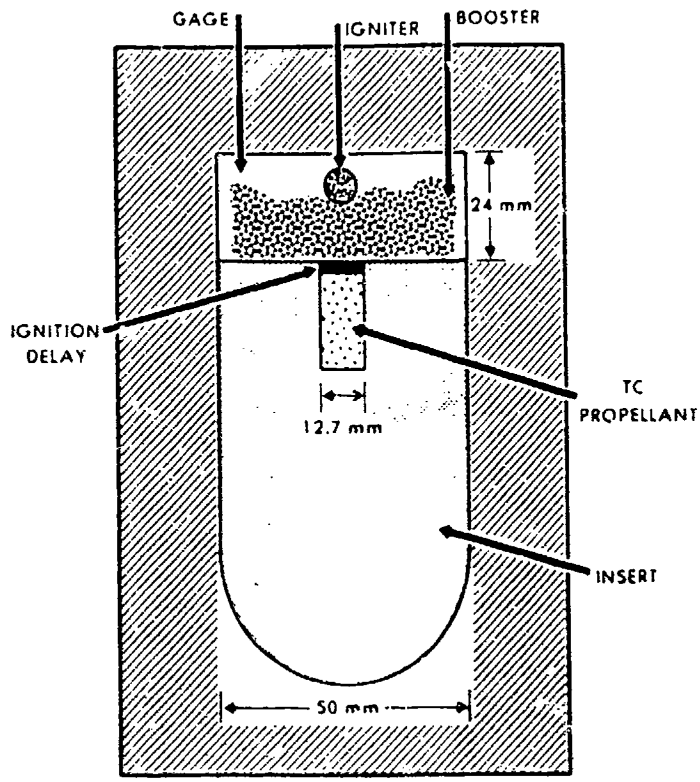

Figure 2. Closed Chamber Schematic

3. RESULTS

The purpose of these tests was to,

(a) determine the burn time at elevated pressures,
(b) devise an acceptable TC ignition delay device,
(c) examine the effects of large mechanical loads on the integrity of the TC grain,
(d) measure the burn time and ignition delay variability,
(e) determine the effect of sample confinement.

Over forty tests were carried out with various configurations of these samples. The results were different for almost every test making a coherent presentation of the data difficult. Consequently, conclusions will be drawn based on an analysis of specific pieces of data.

The formulations tested in this series are listed in Table 1 (TMD %, percent of Theoretical Maximum Density).

TABLE 1. Traveling Charge Formulations

ID	BINDER	(%)	OXIDIZER	(%)	FUEL	(%)	TMD (%)
TMS-1	C4000	10	TAGN/HMX	28/47	H498	15	95
TMS-2	C4000	5	TAGN/HMX	30/50	H498	15	95
TMS-6	GAP/AF	3.5/1.5	TAGN/HMX	30/50	H498	15	95
TMS-7B	C4000	5	TAGN	84.5	H466	10.5	98
TC-14	KRATON	15	RDX	73	H466	12	100
TC-15	KRATON	10	RDX	78	H466	12	100
TC-16	KRATON	5	RDX	83	H466	12	100

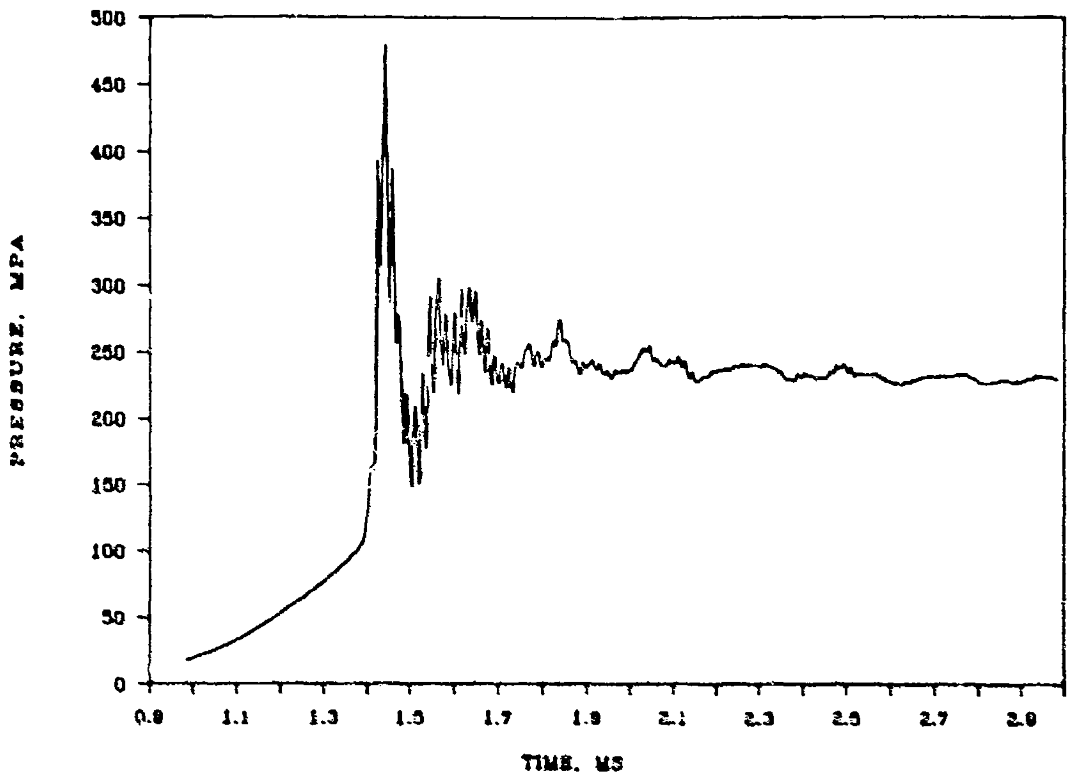

Figure 3. TMS-1: Booster Loading Density, 0.14 g/cm^3

An example of a pressure-time history for TMS-1 is shown in Figure 3. The booster pressure should have reached 170 MPa but it is lear that ignition of the TC sample took place at slightly over 100 MPa. Furthermore, the loading density of the booster and TC was such that the peak pressure should have been 250 MPa. Pressure oscillations reached 470 MPa, with strong high frequency oscillations superimposed. Clearly this is a pressure wave caused by sudden large gas generation. It is

speculated that the sample deconsolidated just as ignition was taking place leading to a large surface area and rapid pressurization rate. All the TMS samples listed in Table 1 as well as TC-16 showed similar behavior.

Figure 4 is a pressure history of sample TC-14 burned under two booster pressurization conditions. For a booster pressure of 170 MPa, the TC ignition delay was 4.6 ms and the burn time was 10.2 ms. For booster pressure of 340 MPa, the delay time was 9.2 ms and the burn time was 1.02 ms. Thus doubling the booster pressure caused a decrease in burn times of identical samples by a factor of 10.

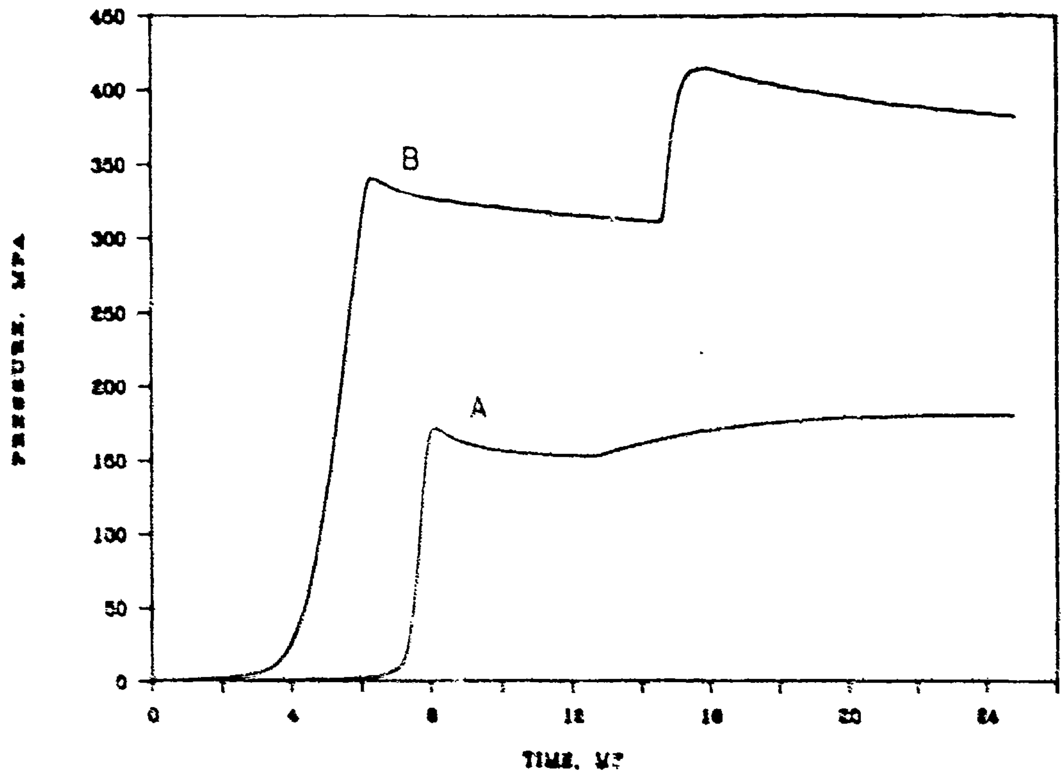

Figure 4. TC-14: Booster Loading Density
(a) 0.14 g/cm^3.
(b) 0.26 g/cm^3.

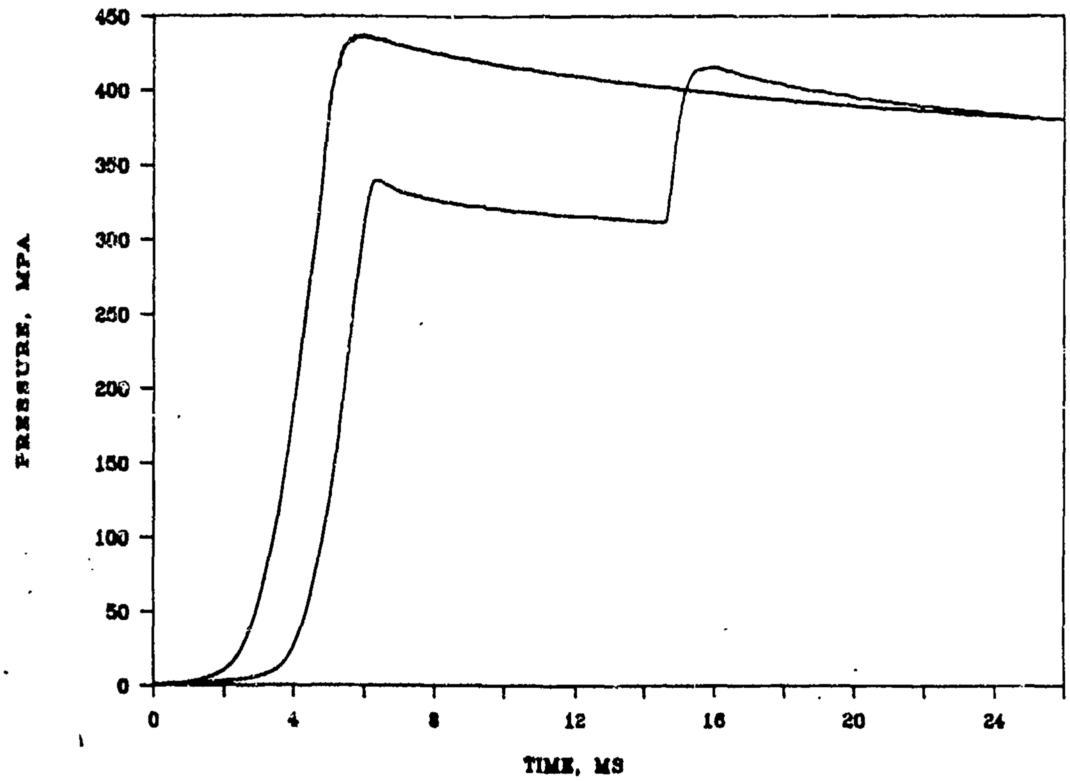

Figure 5. TC-14: Burn Time Reproducibility Test

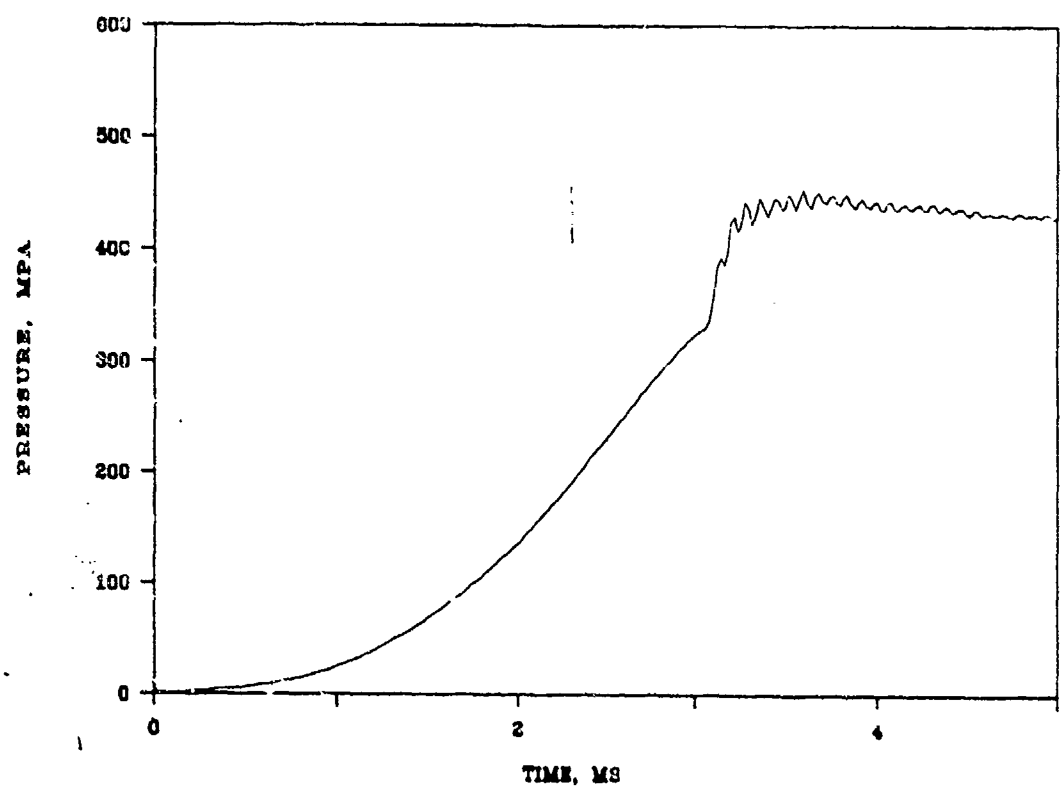

Figure 6. TC-15: Booster Loading Density, 0.26 g/cm^3

Figure 5 illustrates the reproducibility of the burn times of TC-14. The ignition delays were different (9.2 ms vs. 0.74 ms). However, the burn times were nearly the same. For three separate tests the burn times were, 1.02, 0.97 and 1.16 ms.

Figure 6 gives the test results using sample TC-015 at 100% TMD. The booster pressure was 340 MPa. Ignition of the TC took place just at the maximum booster pressure. The burn time measured was 0.5 ms. The pressure rise was so rapid that a chamber oscillation of approximately 12.5 kHz is superimposed on top of the pressure rise. (The resonant frequency for the 24-mm long cavity filled with products at the combustion flame temperature is approximately 20 kHz. However, this calculation does not take into account the alteration of the resonant frequency due to the presence of the sample cavity.) Several other tests were carried out under similar conditions but the ignition of the TC took place prematurely at 200 MPa rather than at 340 MPa. Consequently, the pressure records show a superposition of the burning of both the booster propellant and the TC. Such superposition prevents measuring the burn time of the TC.

If the end-burning cylindrical VHBR samples were to burn in a laminar one-dimensional manner then the pressure time curve should be nearly linear or, if there is a conventional pressure dependence, the slope should be increasing with time. It is obvious from Figures 4, 5 and 6 that this is not the case. In fact, the slope is decreasing with time. This is consistent with the model reported earlier[14] that the sample burns porously followed by a deconsolidation where a large number of particles burn regressively. This would result in a pressure-time curve with a decreasing slope.

Other closed chamber tests[13] with slower burning boron-hydride formulations have shown similar behavior. When burn rates versus pressure were derived from the pressure histories, they were found to depend more on mass fraction burned than pressure. This is consistent with a porous-type burning model.

Table 2 gives the burn time for 25-mm long cylindrical samples at different pressures.

TABLE 2. Burn Time* vs. Pressure

SAMPLE	PRESSURE (MPa)	BURN TIME (ms)
TC-14	0-60	175
	180	12-15
	360	1
TC-15	0-60	133
	180	4
	350	0.5

* sample length, 25 mm.

The initial series of combustion tests on these samples was performed in the low pressure range of 0-60 MPa. With these long burn times the formulations were thought to be unsuitable for TC application. The results of tests at higher booster pressures, however, indicate that these samples have adequate burn times. Formulations that were thought to be too slow were, in fact, acceptable candidates for gun tests. Thus, higher binder content, higher density and lower fuel concentration materials (Table 1) could be used as TC propellants, leading to safer formulations with better mechanical properties. Table 2 shows what appears to be an extraordinarily high dependence of the burn time on pressure. The increasing pressure could cause a larger porous zone or a deconsolidation into smaller particles resulting in a larger gas generation rate. It is not clear at this time how this burning mechanism would effect the TC gun performance.

Tests were conducted to determine if mechanical loading alone could cause ignition and combustion of these formulations. This is an important question to answer since if ignition can be brought about by mechanical loading due to the booster charge, then it will be very difficult to devise an ignition delay device to hold off the VHBR ignition until after the maximum booster pressure. The ignition delay shown in Figure 2 was replaced with silicon grease. This allowed transmission of the mechanical load from the booster but insulated the VHBR sample surface from the heat. The booster was fired in this configuration. After releasing the pressure in the bomb, the sample was removed for examination. All samples used in this type of test were found to be intact physically and had shown no signs of combustion. It was concluded that both a thermal and mechanical stimuli were needed to initiate combustion. Consequently, it appears feasible to design an ignition delay device for the VHBR.

In a TC gun fixture the sample is to be attached to the rear of the projectile. A number of questions arise concerning the propellant-projectile interface. Should the sample be fixed in a sleeve or free to move? Would the booster pressure alone keep the sample attached to the projectile base? To examine the various options, some samples were held fixed by epoxying them into the insert (Figure 2). With others, the sides were greased (silicone) and the sample was placed in the propellant cavity in the insert. In the case of TC-16, when the sample sides were coated with silicone grease, the burn time was 4 ms. When the sample was epoxied in place, however, the burn time was under 100 microseconds. For TC-15, the burn time with silicone grease was 20 ms (at 180 MPa) compared with 4 ms using epoxy (Table 2). Effects such as these have been previously observed by Fisher[15] and Frey.[16] Using x-rays, Frey noted that with greased sides the propellant burned almost intact but that with epoxy the sample broke up into small pieces. Thus, it appears that, as combustion commences, a stress is induced in the sample, or at the base of the sample. If the sides are greased, the sample moves out of the cavity. If it is held fixed, the stress produces a deconsolidation of the sample, with subsequent rapid pressurization.

4. CONCLUSIONS

The conclusions from the diagnostics can be summarized as follows;

* Very rapid ignition and combustion occurs with TMS 1, 2, 6 and 7B and TC-16 with booster pressures of 120 MPa.

* Ignition and combustion were observed under combined shear/thermal load.

* Shear forces alone are insufficient for ignition.

* Side confinement and immobilization of the sample are required for rapid burn.

* The burn time is strongly dependent on the booster pressure.

* Reproducibility of TC-14 may be adequate for the traveling charge.

* Although some control of ignition delay times has been achieved, a reproducible ignition delay unit has not yet been designed.

* Samples TC-14 and TC-15 appear to be possible candidates for TC gun applications.

As a result of these tests samples TC-14 and TC-15 were selected for gun firings. When an ignition delay device was employed, the 1-mm thick NOSOL 265 disc was used.

III. TRAVELING CHARGE BALLISTIC FIRINGS

1. BACKGROUND

As was mentioned in the Introduction, the choice of the readily available, 12.7-mm diameter VHBR propellant as the traveling charge propellant dictated that the gun system would have to be a small bore fixture. The projectile should have the charge attached to the base. In previous closed chamber combustion work[13] of VHBR propellants, the samples were contained in steel sleeves. In many tests the sample burned so rapidly that the steel sleeve expanded or ruptured. It became obvious that a sleeve of practical dimensions attached to the base of the projectile would not be strong enough to confine the sample. This result prompted the use of a very thin walled holder, attached to the projectile base, for the propellant in the gun firings. The barrel then acted as a circumferential constraint for the traveling charge. Additionally, this allowed us to minimize parasitic mass on the projectile. An interior ballistic code, XNOVAKTC (XKTC),[17] was used to aid in the determination of the barrel length and to model the proposed chamber configuration and booster combinations. This program has been used successfully to model the effects of gun geometry and charge

packaging on the interior ballistic process. The code was used to minimize the initial combustion start up perturbations and oscillations that can occur in a gun chamber. The XKTC code predicts a nominal 3 milliseconds total action time for the projectile until muzzle exit.

2. EXPERIMENTAL

A schematic of the gun fixture, with pressure port locations, is shown in Figure 7. The bore diameter is 14 mm. The smooth-bore barrel length is 2900 mm. A conventional propellant, to be ignited in the 100 cm^3 chamber, provides the initial acceleration to the projectile. The fixture was autofrettaged to 1100 MPa and then seven pressure ports located along the wall of the gun were machined and tested to 700 MPa.

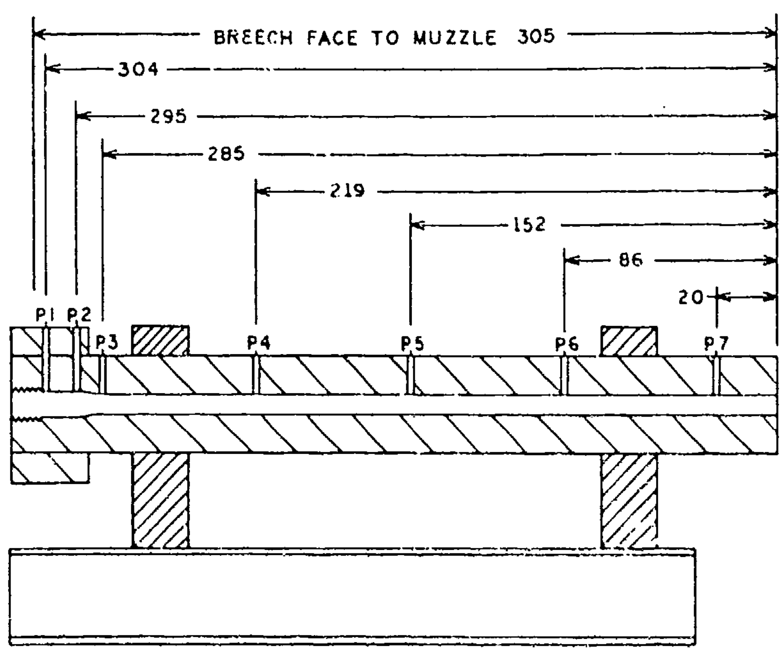

Figure 7. Solid Propellant Traveling Charge Gun Fixture Schematic. (Distances in cm)

The projectile used for the first series of shots is shown to scale in Figure 8. It was constructed in three sections of aluminum with double nylon obturators. The length of the traveling charge holder is adjustable, depending on whether a 25-mm or 50-mm sample is used. The overall projectile length when using a 50-mm sample of VHBR propellant is 110 mm. The nominal mass of the unloaded projectile is 22 grams.

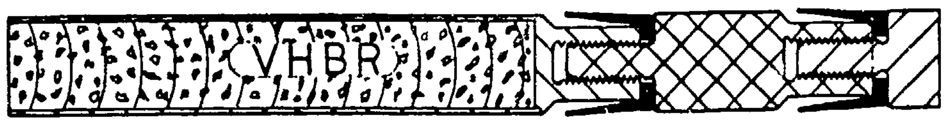

Figure 8. Solid Propellant Traveling Charge Projectile

The chamber configuration, with the bagged booster charge and projectile, is shown in Figure 9. The final dimensions were chosen to facilitate loading, simplify igniter requirements, and minimize pressure oscillations. Several calculations were done using the XKTC code that varied the chamber dimensions and the placement of the booster charge to minimize the possibility of pressure oscillations.

The booster propellant used for the gun firings was a non-deterred, unrolled small arms propellant. This non-deterred propellant was used to simplify the interior ballistic calculations.

Data acquisition is done on analog tape, which is later digitized and reduced by the BALDAS (Ballistic Data Acquisition System) data reduction code. The gun pressures are measured with Kistler 607C piezoelectric gauges. Velocity is measured using both a 35 GHz microwave interferometer and break screens. High speed cinematography is also available using a Photec high speed motion picture camera.

The operation of the fixture is as follows. The booster charge is prepared by bagging 1.5 grams of class 6 (FFFG) black powder with an M-100 Atlas electric match in a small dacron cloth bag and installing this igniter in an already prepared polyethylene film tube that has been sealed at one end. This tube is then filled with the booster charge. The leads of the electric match are left protruding from the open end of the tube and the film is sealed around the leads and booster charge. The match leads are then attached to an electric feedthrough device in the breech closure head. The projectile, with the VHBR propellant epoxied into the tailstock, is now positioned in the barrel with a tool that assures reproducible location of the back end of the projectile. The breech closure head, with the booster charge attached, is installed and sealed. A 34-gram booster charge and a 1.5-gram igniter was chosen for all tests. When an inert simulant was used in place of the VHBR, the total projectile weight was 24.6 grams. This gave a charge-to-mass

ratio of approximately 1.4. A large ratio such as this was chosen to give a large pressure drop between the chamber and the projectile. These conditions make it easier to discern any increase in base pressure due to combustion of the VHBR propellant.

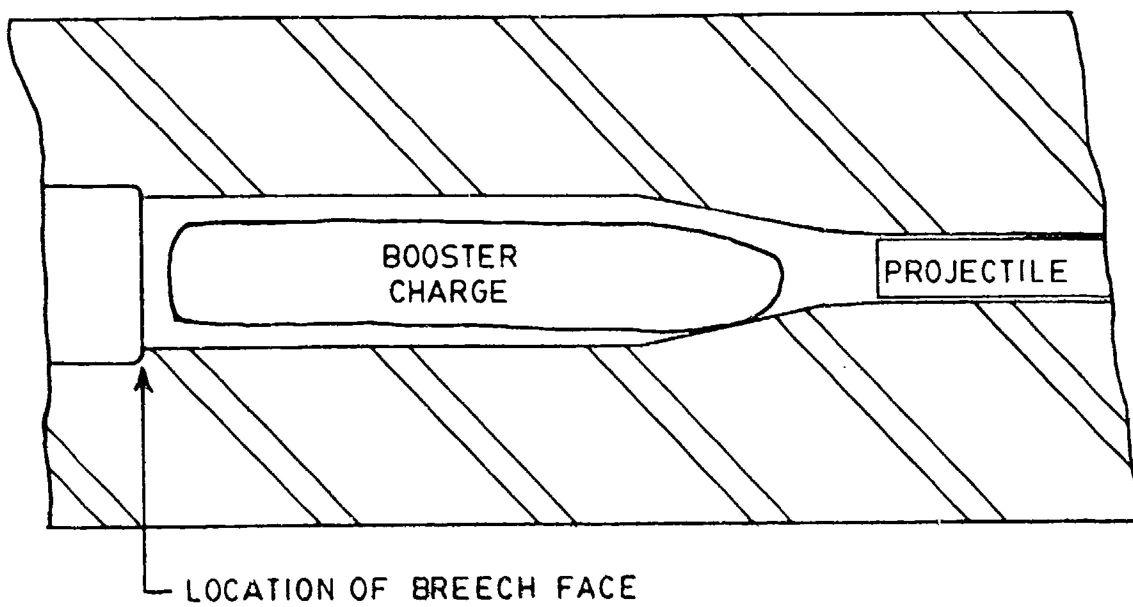

Figure 9. Chamber of 14-mm TC Gun

3. RESULTS

The primary objective of the gun firings is to increase the muzzle velocity by increasing the down bore pressure. Additional questions to be answered concerned projectile integrity and the effects of using an ignition delay on the VHBR.

The results of the gun firings are summarized in Table 3. Two conventional charge (all-booster) computer calculations are also included for comparison purposes.

TABLE 3. Comparison of Experimental Gun Firings to Computer Simulations.

ID	VHBR	MASS (g)	MAX. PRESSURE (MPa) breech	mid-tube	muzzle	VELOCITY (m/s) from interf.
5	inert	3.6	335	71	29	1565
6	"	3.6	340	71	28	1570
34-g Calculation			(341)	(65)	(28)	(1570)
7	TC-14	4.5	360	76	[illegible]	1650
8	TC-14	4.5	360	78	39	1620
9	TC-14	8.0	375	82	38	1630
10	TC-14	8.0	380	82	37	1610
42-g Calculation			(496)	(75)	(37)	(1813)
11*	TC-15	8.0	500	100	42	1680
12*	TC-15	8.0	555	98	44	1640

* - Ignition delay used on TC.

As can be seen in the above table, the pressures are reproducible within duplicate shot sets. Additionally, the increase in down bore pressures would indicate that the use of VHBR propellant as a traveling charge component shows possibilities based on this limited number of gun firings.

The velocity data in Table 3 was taken from the interferometer records. Unfortunately, due to propellant gases passing around the obturator, the microwave signal from the interferometer was lost in the latter part of the ballistic cycle on run ID 9 thru 12. The overall shape of the velocity-time curves can be readily seen, however, from similar plots for runs where no leakage occurred. The velocities for ID 9 thru 12 in Table 3 are corrected values based on extrapolation of the velocity record to the muzzle gauge (see Figure 10). Any errors in extrapolation are expected to be less than $\pm$ 30 m/s. Although additional velocity measurements were made using break screens, the data was discarded because high speed films indicated that the projectile and/or the VHBR propellant was burning out of bore. This could have given additional thrust and altered the velocity.

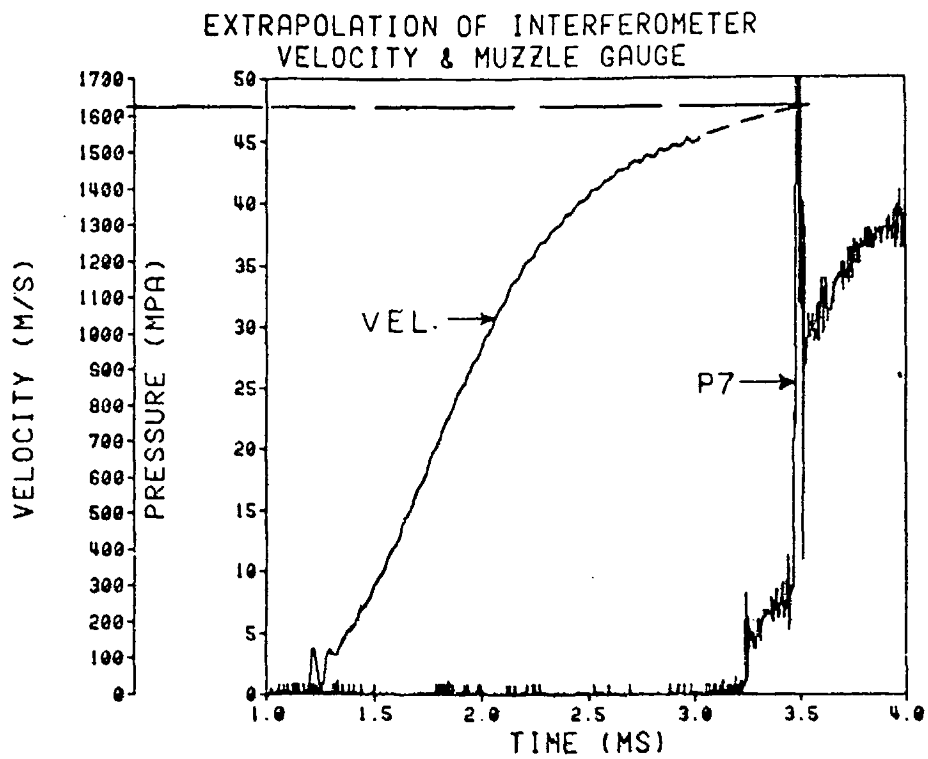

Figure 10. Plot of Velocity vs. Time from the Interferometer and Pressure vs. Time from P7. Data from ID 9.

The VHBR inert simulant firings (ID 5 and 6) were carried out as a baseline case for the traveling charge and to calibrate the XKTC calculations. As can be seen in Table 3, the 34-gram all-booster calculations compare well to those experimental results.

The first VHBR propellant to be fired in the gun fixture was TC-14. The initial samples were 25 mm long with a mass of 4.5 grams. This formulation was well behaved and had demonstrated burn times, at 300 MPa in closed chamber testing, that were compatible with traveling charge requirements. There was no ignition delay used on the TC-14 samples. The initial firings appeared promising so an 8-gram sample was used for the next series.

The results of firings using the TC-14 propellant are included in Table 3 (ID 7-10). The velocities increased over the all-booster results of ID 5 and 6. The pressures also increased, indicating simultaneous burning of the booster and at least part of the VHBR propellant. The lack of ignition delay on the TC-14 samples forced the TC pressure record to be superimposed over the booster pressure-time curve (see Figure 11).

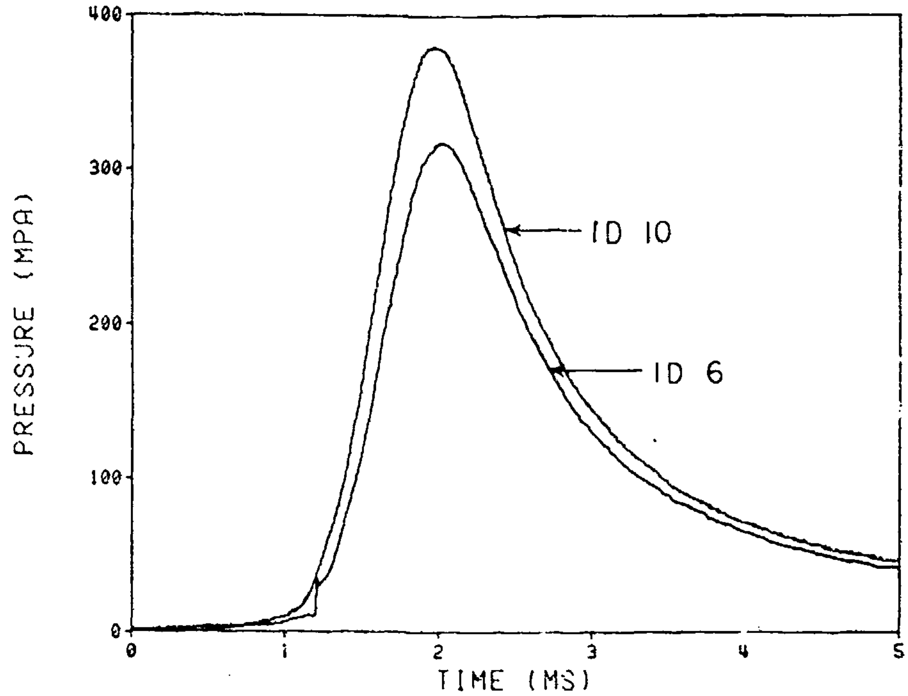

Figure 11. Chamber Pressure Histories of a Conventional Firing (ID 6) and a TC Firing with no Ignition Delay on the TC (ID 10)

For purposes of evaluating traveling charge behavior, an important test is the comparison of an all-booster firing with a booster/VHBR firing of equal total propellant mass. (This assumes that the energies of the booster and VHBR propellant are identical.) Unfortunately, at this time the 42-gram all-booster experimental data are not available. However, the 42-gram all-booster case may be simulated by XKTC calculations, as was the 34-gram all-booster case, with reasonable assurance of accuracy. A comparison of a 42-gram all-booster calculation with firings 9 and 10 can be made from Table 3.

This comparison shows a much higher chamber pressure from the all-booster calculation (25%) relative to firings 9 and 10. The down-bore pressures of 9 and 10 show a slight increase relative to the all-booster calculation. This indicates that the traveling charge element burned down-bore as intended, rather than at the chamber. Although the pressure-travel profile was modified in the desired direction, the velocities from these firings were not increased as desired. The reason for this is unclear but possible causes will be discussed later in this report.

Calculations[12] have shown that the location of the onset of combustion of the VHBR propellant is very important for a traveling charge effect. For that reason, an ignition delay element was used on the VHBR propellant for firings 11 and 12. A formulation with a shorter burn time, TC-15, was therefore used as the traveling charge component. As can be seen in Table 3, the pressures for numbers 11 and 12 have all increased over the previous experimental results. The pressures are also higher than those reported from the 42-gram all-booster calculation.

Composite plots of pressure vs. time data for ID numbers 5 and 11 are shown in Figures 12 and 13 respectively. Figure 12 is a plot of data from a VHBR inert simulant firing while Figure 13 is a data plot from a firing of 8 grams of TC-15 with a nominal ignition delay of 1 millisecond for the VHBR. Figure 13 shows some fairly high pressure spikes in the chamber and at bore origin (P1, P2, and P3) that are not present in Figure 12. These spikes are actually the signature of a pressure wave that starts at P3 and moves toward the breech. This wave is due to the ignition and combustion of the TC-15 propellant and does not occur unless an ignition delay element is used on the VHBR propellant.

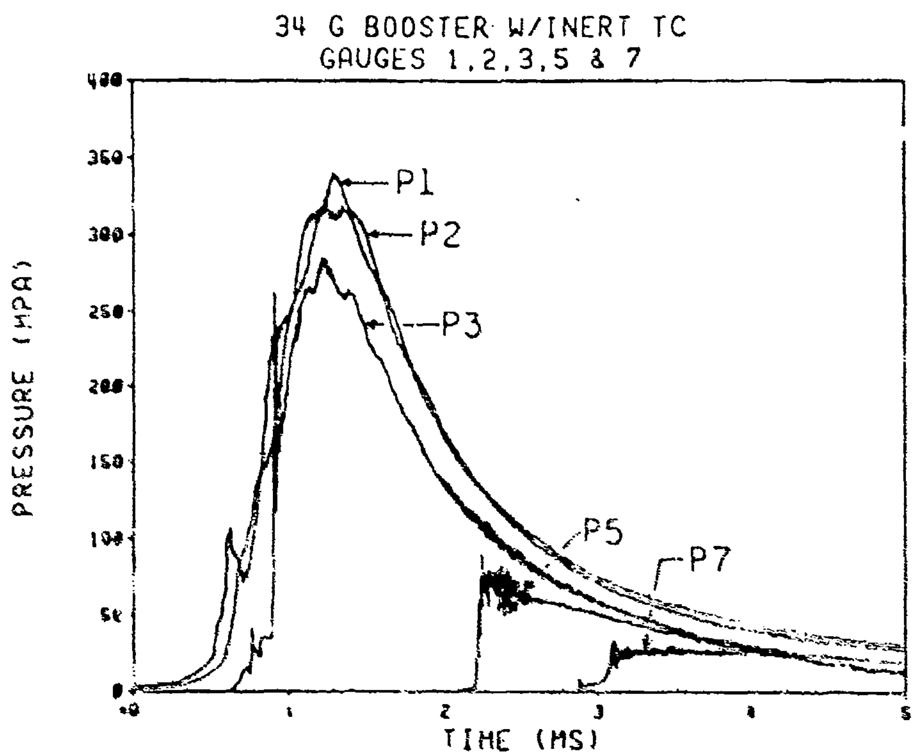

Figure 12. Pressure vs. Time Data from Gun Firing ID 5.

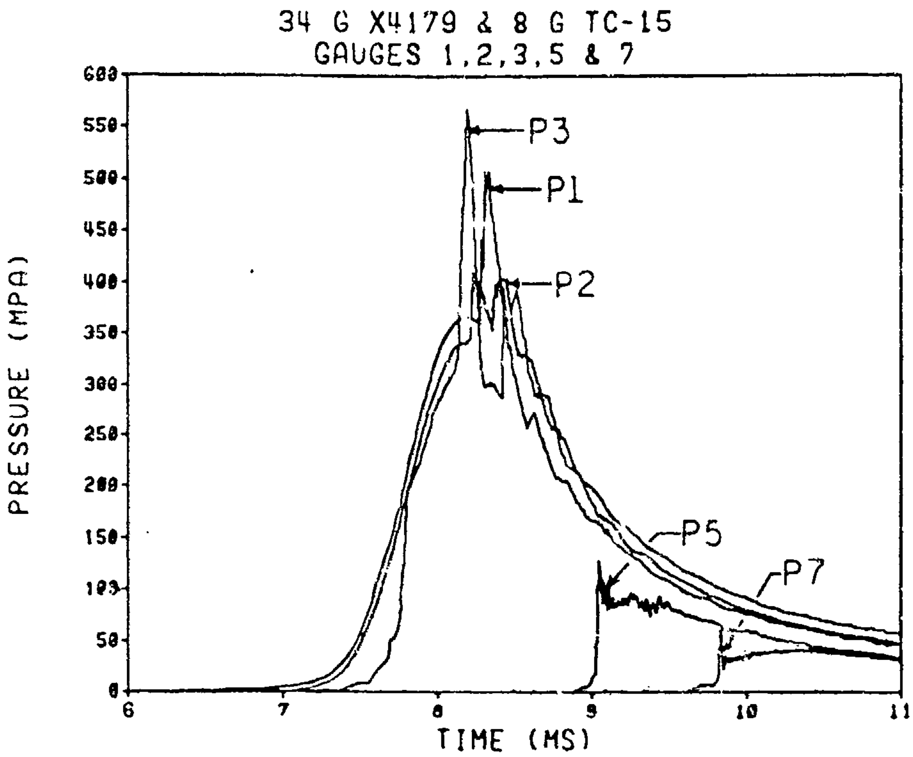

Figure 13. Pressure vs. Time Data from Gun Firing ID 11.

One of the most gratifying pieces of data from the study is the projectile acceleration data from firing ID 12. Figure 14 shows superimposed acceleration vs. time curves for an all-booster firing (ID 6) and a TC-15 firing with an ignition delay element (ID 12). The burning of the VHBR propellant is expected to impart additional acceleration to the projectile. Figure 14 clearly shows the desired acceleration from the VHBR burning.

While the pressure records have shown an increase in down bore pressures, the corresponding velocity records have not shown a significant increase. In fact, the experimental velocity results for a traveling charge case are systematically lower than the calculated velocities. It may be possible that the bore resistance for the TC case is substantially larger than for a conventional firing. The propellant holder is 5 cm long and made of thin walled (0.04 cm) aluminum. The normal forces exerted by the VHBR burning can easily exceed 100 MPa which would, in an unconfined situation, rupture the holder. During a gun firing, the aluminum, instead of rupturing, may be forced out to the bore surface when the VHBR ignites and may create a potentially very large bore resistance. Consequently calculations were carried out in which the bore resistance profile was increased. It was possible to decrease the velocity calculated with the computer simulation of ID 12 from 1780 m/s to 1650 m/s by increasing the bore resistance from 20 to

40 MPa. This brought the measured and calculated results into closer agreement. Evidence for a possible bore resistance increase is observed in Figure 15. Here are plotted velocity vs. time for ID 6, booster only, and ID 12, 8-g VHBR TC-15. The curves are the same for the first part of the travel. The velocity for ID 12 increases dramatically with the onset of combustion of the traveling charge. However, slightly later (4.1 ms) the velocity for ID 12 does not increase as much as for ID 6, showing a lower acceleration.

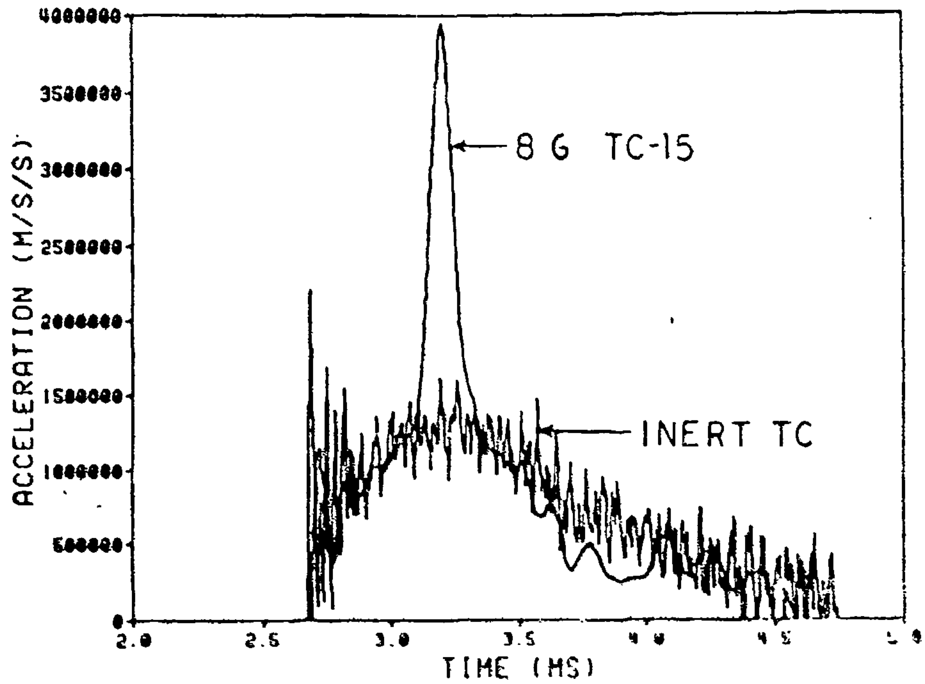

Figure 14. Acceleration vs. Time Plots from Firings 6 and 12 Showing the Acceleration Due to the VHBR Component from ID 12.

There is another possible explanation for the velocity difference that will be investigated in the future. The XKTC code has provisions for allowing an extended reaction zone for the traveling charge combustion. In the calculations reported in Table 3, this option was not exercised. All energy was assumed to be released instantaneously at the TC surface as it burns. An extended reaction zone may have an effect on the predicted pressures and velocities.

There is an additional hypothesis for the velocity discrepancy. If due to depressurization or rapid acceleration, the TC propellant is

extinguished, then the total energy will not be released and the velocity will be lower than predicted. This will be a subject for future investigation.

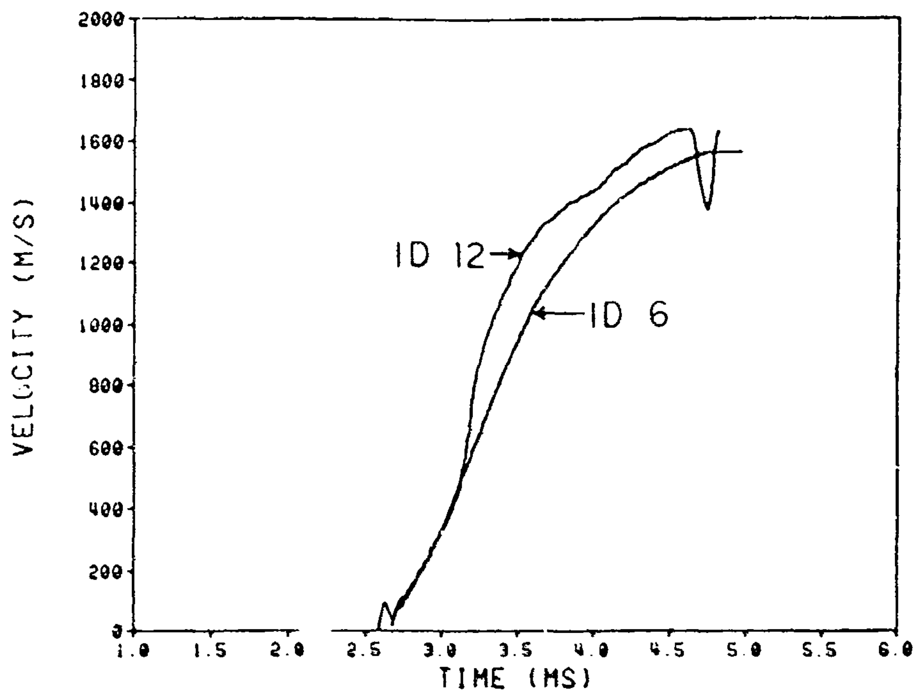

Figure 15. Velocity vs. Time Plots Comparing Conventional Firing Results (ID 6) to Traveling Charge Results (ID 12).

4. CONCLUSIONS

The conclusions from the gun firings can be summarized as follows;

* The reproducibility of both the pressure records and the velocity data within each set of firings is good.

* The pressure data from the firings with the VHBR propellant show a modification of the pressure vs. distance profile in the desired direction.

* There is an overall trend of increasing velocity as the VHBR is increased but the velocity falls short of predicted values.

* The results of firings 11 and 12 have shown an increase in down bore pressure with a simultaneous acceleration demonstrating the beginnings of a traveling charge effect.

IV. FUTURE PLANS

The following are plans for the near future:

* The projectile obturator will be redesigned to reduce blow-by to obtain an accurate velocity record until muzzle exit.

* Flash x-rays will be used at muzzle exit to measure velocities and to examine projectile integrity.

* The TC holder on the projectile will be redesigned to reduce bore resistance.

* The control and reproducibility of the ignition delay of the VHBR propellant will be improved.

* Other calculations will be carried out to investigate the source of the velocity discrepancy.

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